Tropospheric Ozone and Human Health

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Outline

- Brief history of air pollution and human health research
- Tropospheric ozone
- The relationship between ozone and mortality
  - Recent studies
  - Future research directions

Early Air Pollution and Human Health Research

Photos: DL Davis, 2002

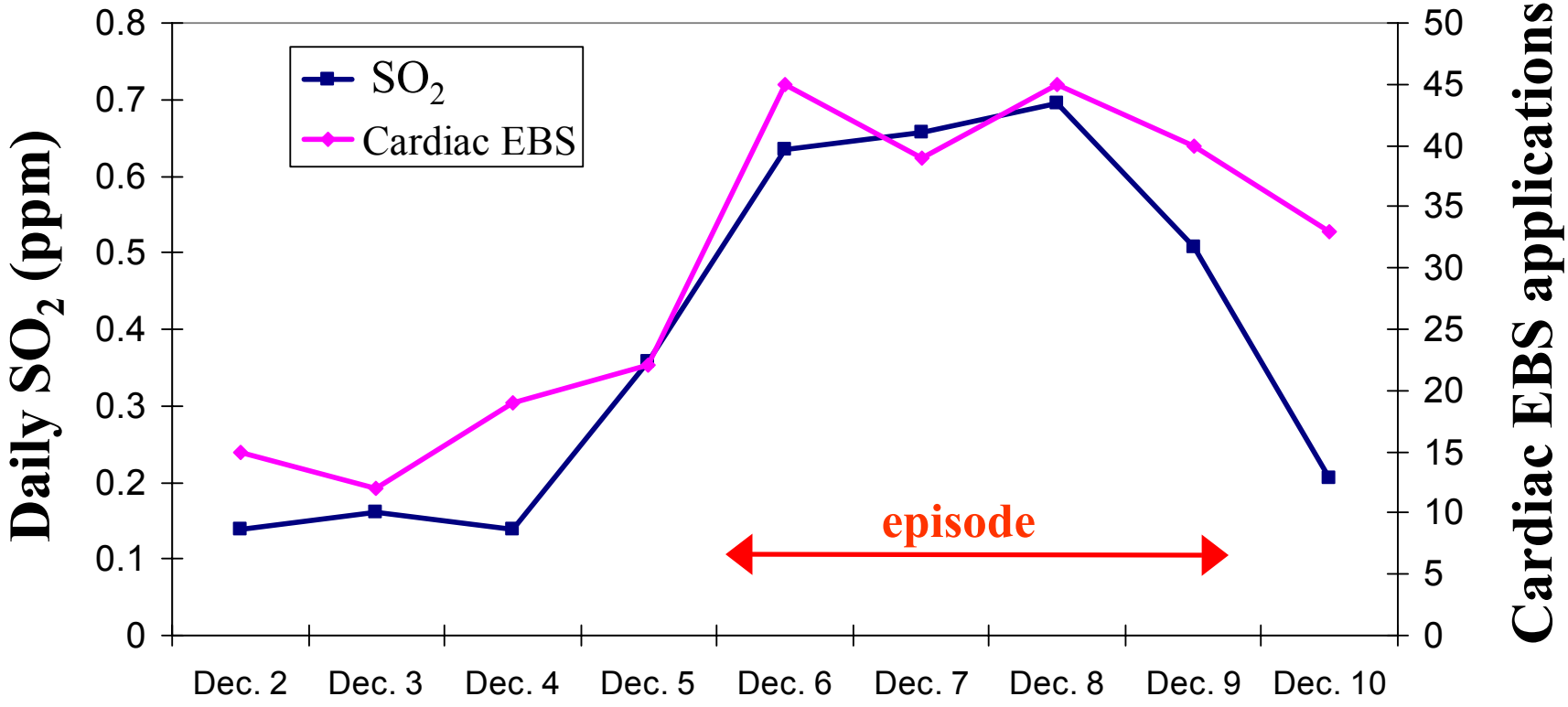
Designer Smog Masks (London 1950's)

Source: DL Davis. *When Smoke Ran Like Water* (2002)

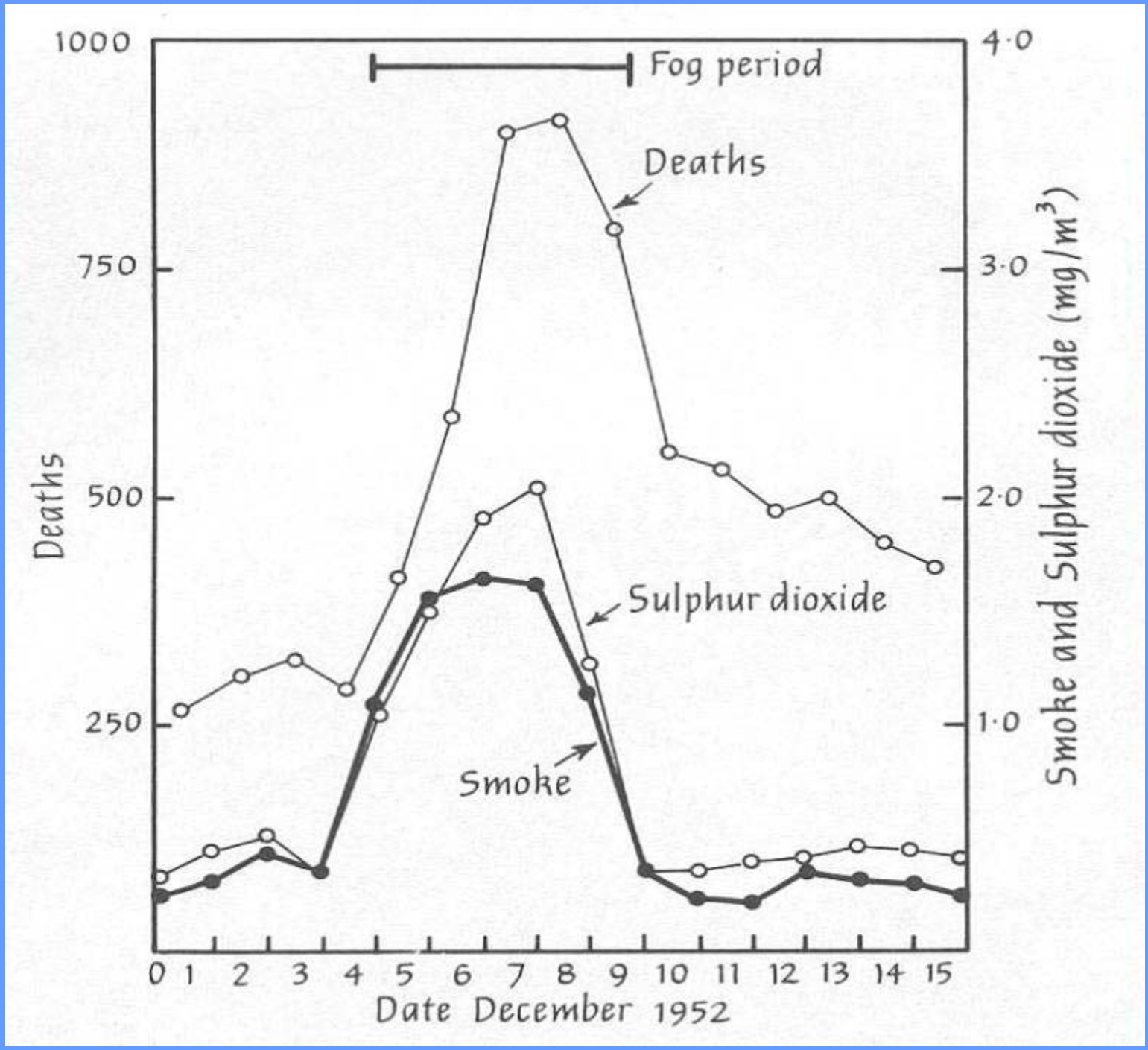
London 1952
10:30am

Source: National Archives

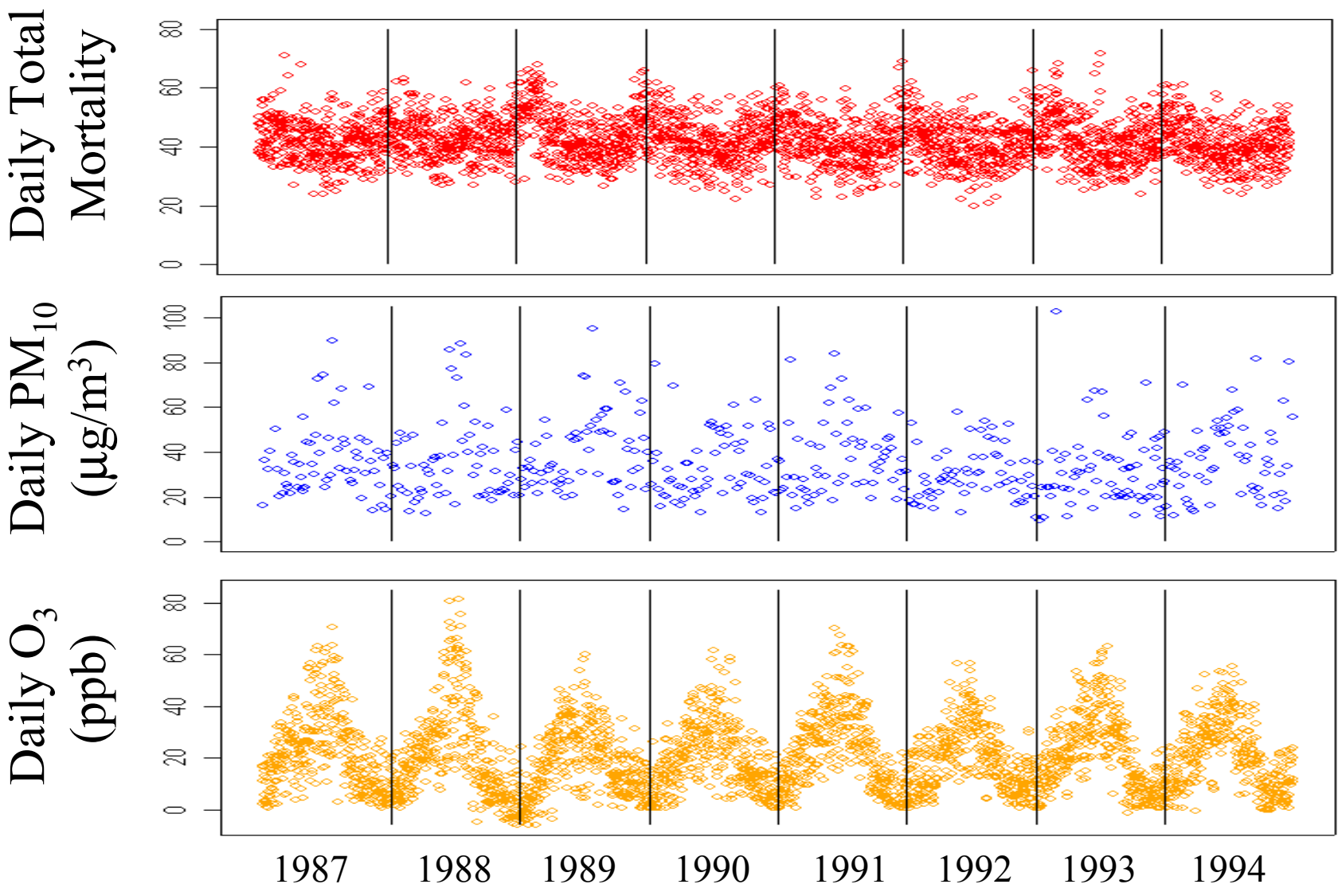
Cardiac Emergency Bed Service Applications for Greater London 1952



Source: Bell & Davis, *EHP* 2001


1000
750
500
250
Deaths
4·0
3·0
2·0
1·0
Smoke and Sulphur dioxide (mg/m³)
Fog period
Deaths
Sulphur dioxide
Smoke
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Date December 1952

Modern Data: Philadelphia (1987-1994)



Source: NMMAPS, Johns Hopkins Bloomberg School of Public Health

Also in 1952: Discovery of Photochemical Smog

- Arie Haagen-Smit (1900 – 1977)
  - Began with study of vegetation damaged by air pollution
  - Discovered that tropospheric O_3 was
    - Not mainly from stratospheric intrusion
    - Not directly emitted but was formed through the chemical conversion of precursors
  - Suggested that O_3 and its precursors were the main constituents of LA smog

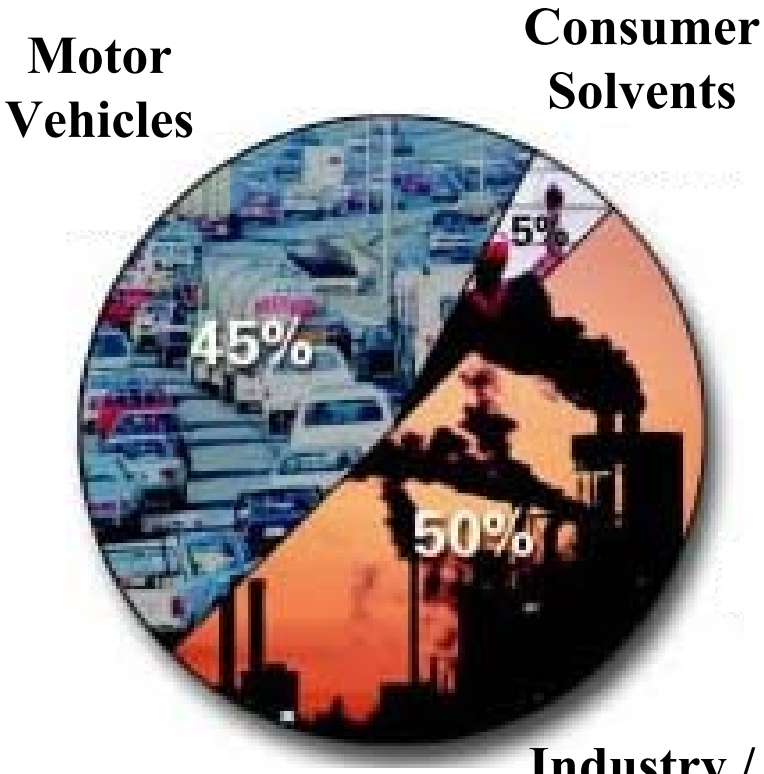
Tropospheric O_3 Chemistry (very simplified)

$$VOCs + NO_x + \text{heat / sunlight} \rightarrow O_3$$

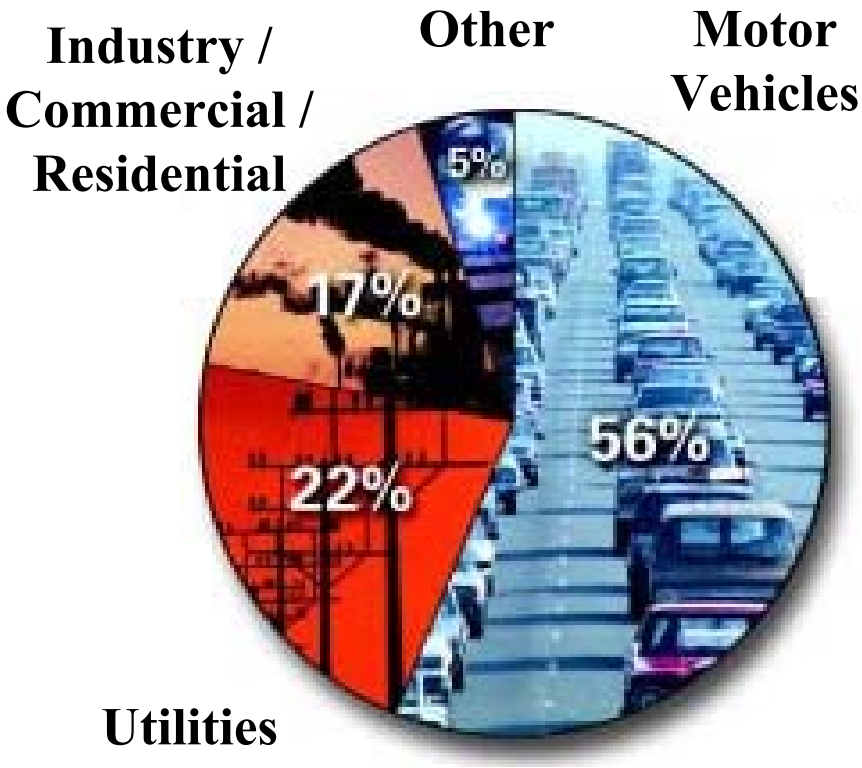
Precursors to ozone

Secondary pollutant

Anthropogenic Ozone Precursors



VOC Sources



NO_x Sources

Source: *EPA 2003*

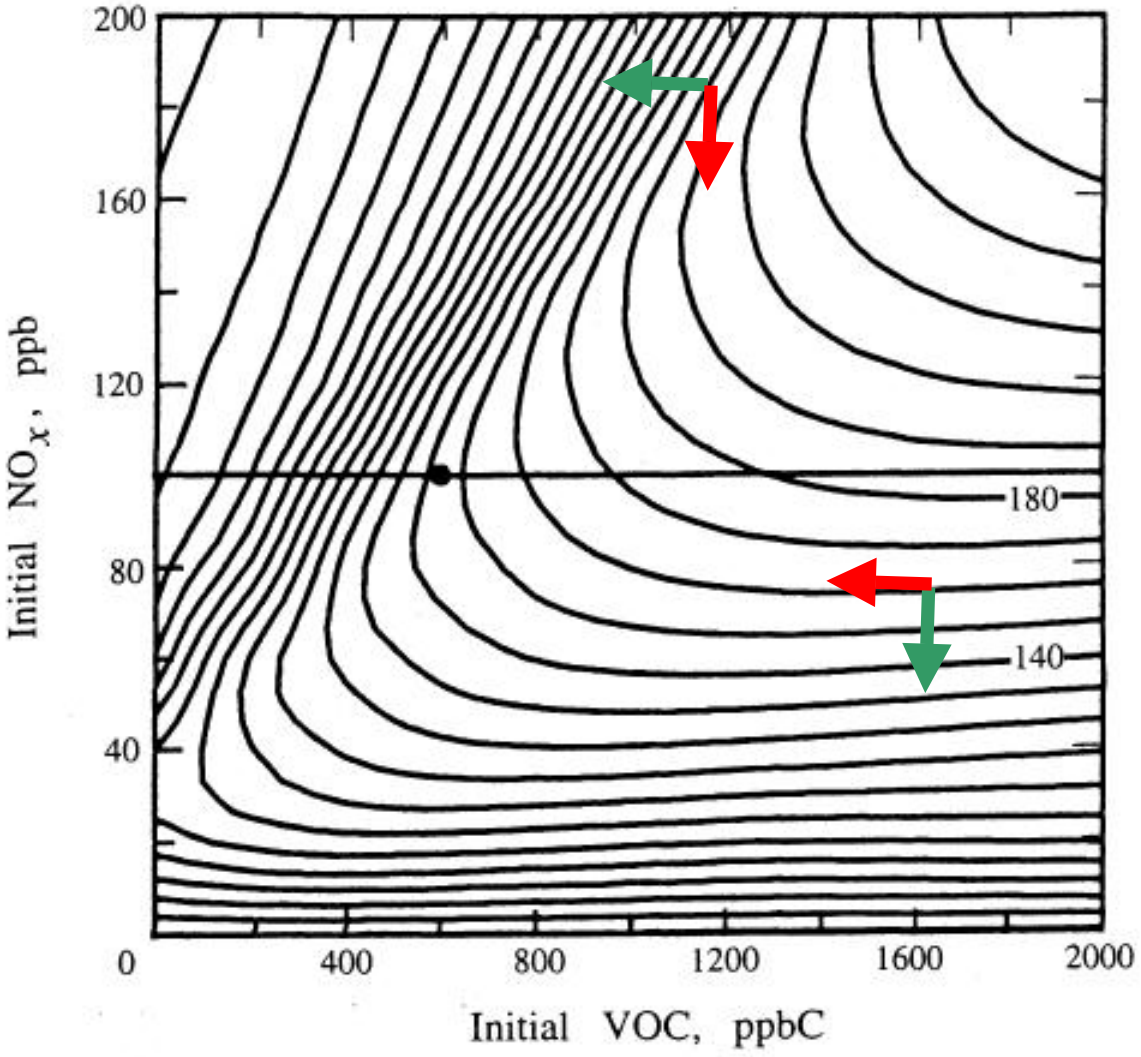
NO_2 and Health

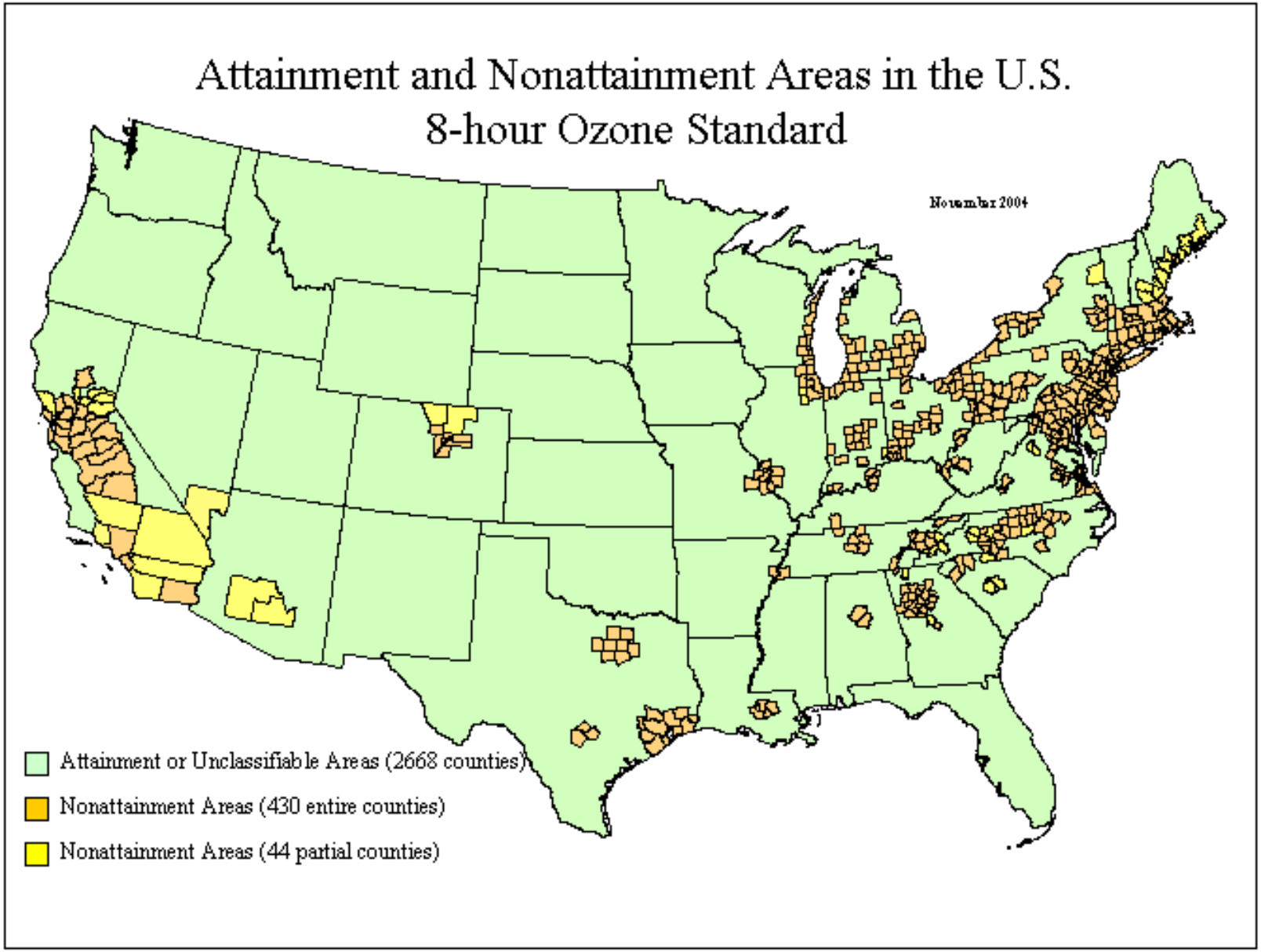
- Health effects: irritation to throat and lungs, respiratory tract infection, exacerbation of asthma, lung function, possible increased susceptibility to allergens
- Children and asthmatics more susceptible
- Also a Criteria Pollutant

Volatile Organic Compounds (VOCS)

- Category of pollutants
- Gas
- Primary, secondary
- **Sources:** Biomass and fossil fuel combustion, construction materials, household chemicals (solvents), industry, biogenic sources
- **Health effects:** headache, dizziness, upper respiratory tract irritation, nausea, cancer

O_3 Isopleth Plot





Source: *EPA Greenbook*

Health Impacts of Ozone

- Effects on lung function
- Respiratory symptoms
- Exacerbation of asthma
- Hospital admissions
- Emergency room visits
- **Mortality?**

Source: EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants*. **1996**

Why divergent results for ozone and mortality?

- Potential reasons:
  - Differences in (and lack of) statistical power
  - Various statistical methods
  - Addressing of potential confounders
  - Underlying populations
  - Health care systems
  - Data quality
  - Others?

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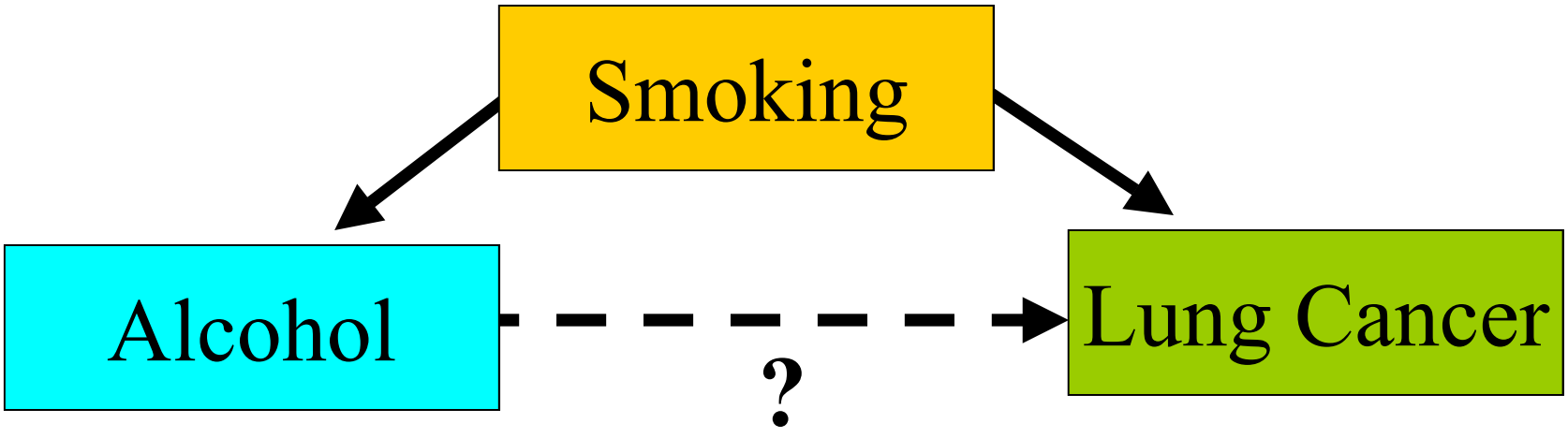
Confounders

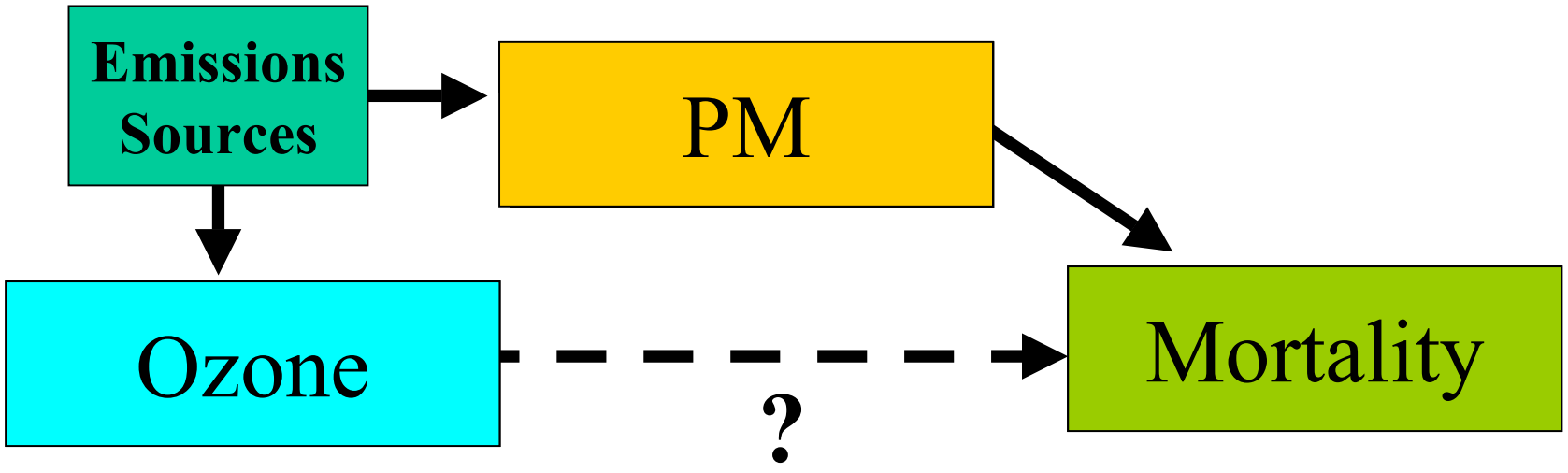
- Potential confounder
  - Associated with the exposure of concern
  - Associated with the health endpoint
  - Not in the causal pathway
- Can create spurious associations or obscure real associations

Confounding Example

- What is associated with *both* the exposure and the health outcome?
  - Could potentially be a confounder



Potential Confounders for Ozone and Mortality



Approaches to Resolve Seemingly Conflicting Results

1) Meta-Analysis

   Combine results of previous efforts

   + Increased statistical power

   + Can explore differences in model specification, location, etc.

   - Publication bias

2) Multi-City Study

   Estimate the relationship in numerous locations

   + The above advantages

   + Lack of publication bias

   - Data intensive

1) Meta-Analysis Approach

- Systematically review the literature to find studies
- 144 effect estimates from 39 time-series studies
  - 38 in the U.S., 106 from outside the U.S.
- Combine the estimates using a Bayesian hierarchical model

$$\hat{\beta}^s \mid \beta^s, v^s \sim N(\beta^s, v^s), s = 1,\ldots, S$$

$$\beta \mid \mu, \tau^2 \sim N(\mu, \tau^2)$$

Plus sensitivity analysis to model structure and distributions . . .

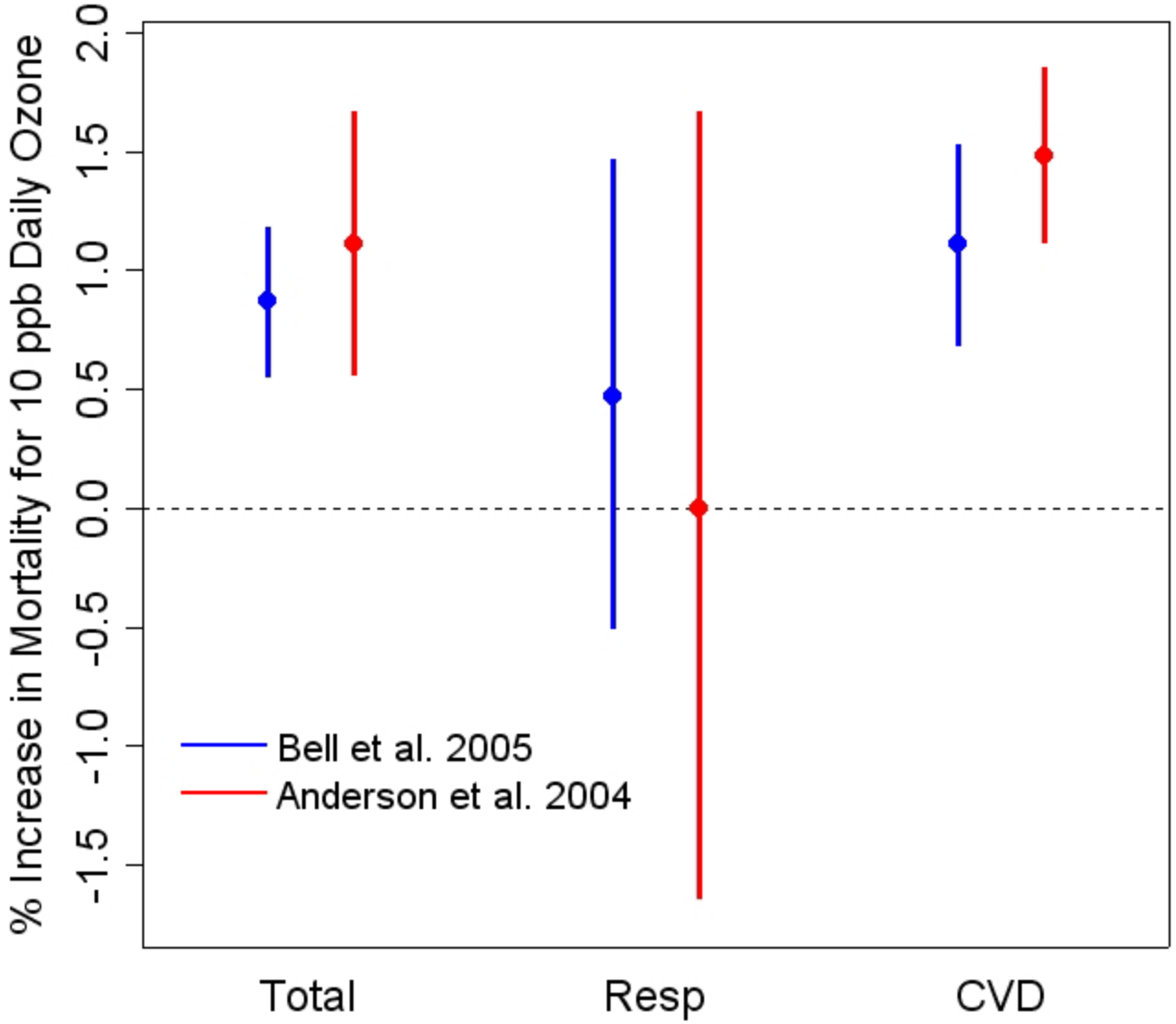
Source: Bell et al., *Epidemiology* 2005

Results by Cause

- Percent increase in daily total mortality for a 10 ppb increase in daily ozone (95% CI)

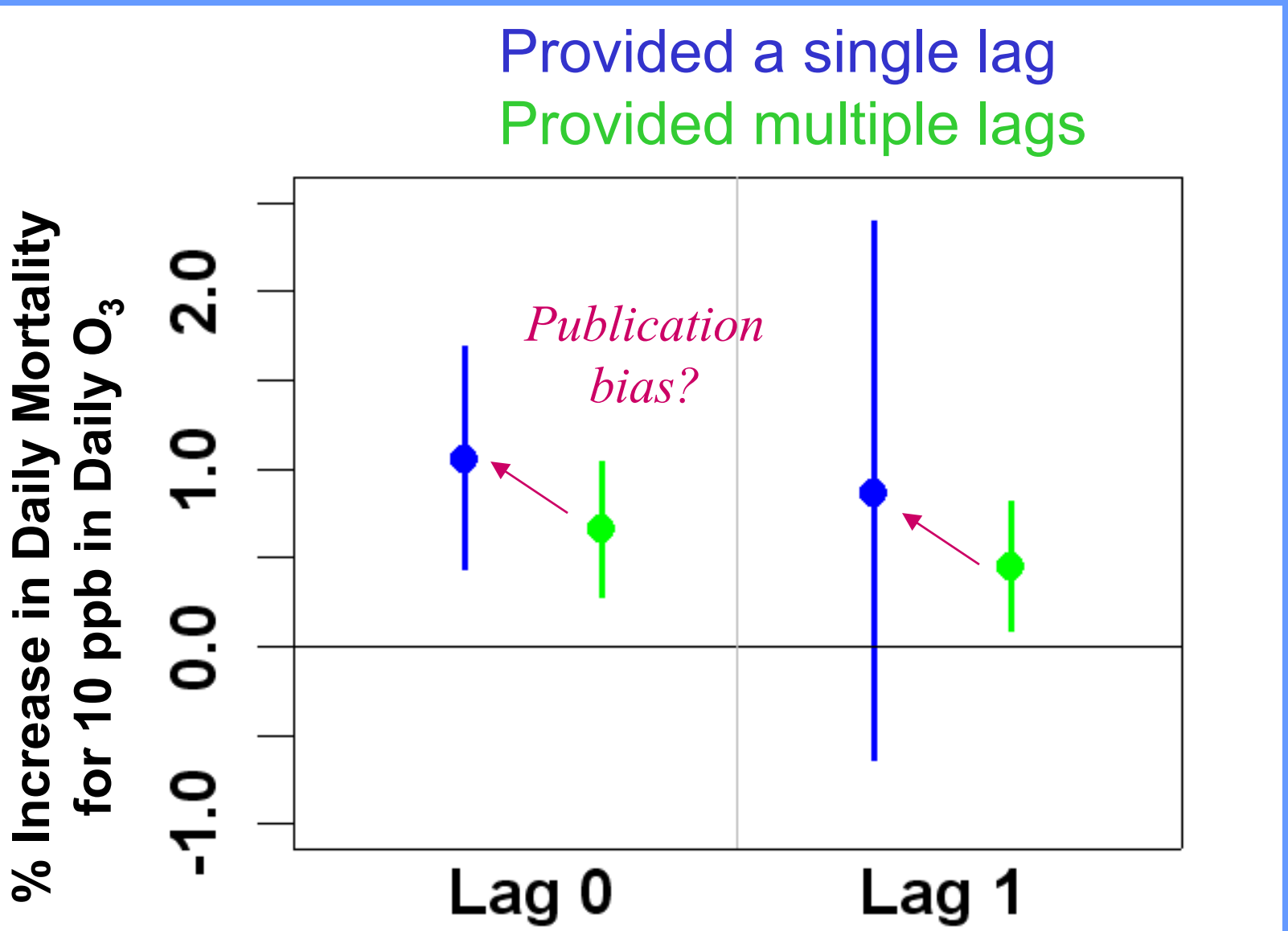
- Total: **0.87% (0.55, 1.18%)**
- CVD: **1.11% (0.68, 1.53%)**
- Respiratory: **0.47% (-0.51, 1.47%)**

Comparison to Anderson et al. *WHO* Report (2004)



Other New Meta-Analyses

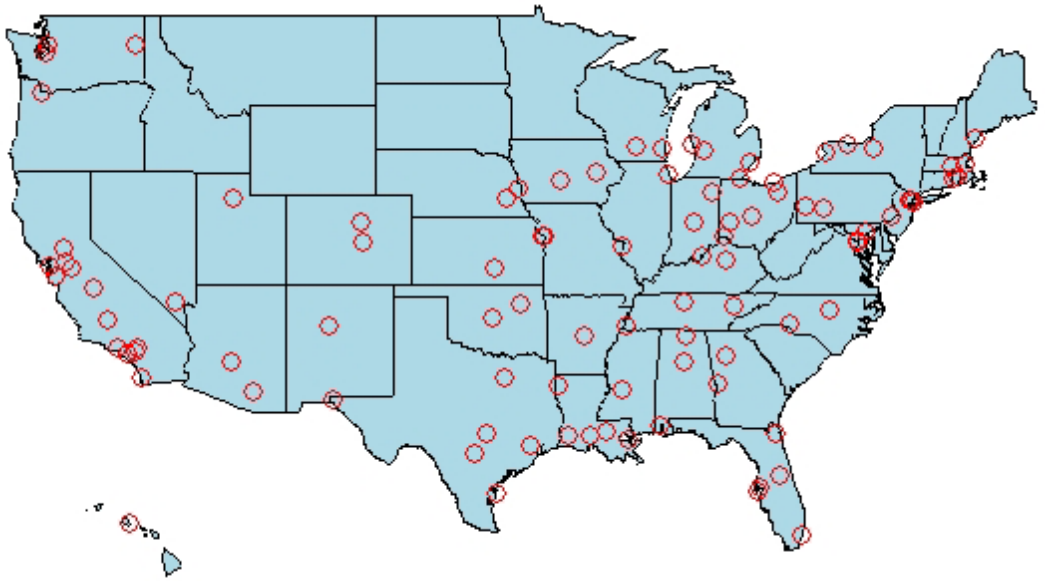
- **Jonathan I. Levy**, Susan M. Chemerynski, Jeremy A. Sarnat (2005). Ozone exposure and mortality risk: An empirical Bayes meta-regression analysis. *Epidemiology* 16(4).
- **Kazuhiko Ito**, Samantha DeLeon, Morton Lippmann (2005). Associations between ozone and daily mortality: A review and additional analysis. *Epidemiology* 16(4).


Provided a single lag
Provided multiple lags
% Increase in Daily Mortality for 10 ppb in Daily O_3
-1.0
0.0
1.0
2.0
Publication bias?
Lag 0
Lag 1

Selected Meta-Analysis Results

- 144 effect estimates from 39 time-series studies
- Strong statistically significant association identified between ozone and mortality for total deaths and cardiovascular disease
- Implied relationship between ozone and respiratory disease mortality
- Large heterogeneity in individual study estimates
- Strong indications of publication bias

2) Multi-City Study



- Time-series study to investigate short-term exposure to ambient ozone (up to a week)
- 95 large urban U.S. communities (40% of the U.S. population)
- 14 years of daily data from 1987 to 2000
  - Some cities monitor O_3 for part of the year
- Uniform analysis framework for all cities
- Total and Cardiovascular/Respiratory mortality

Source: Bell et al., *JAMA* 2004

Hierarchical Approach

- Stage 1
  - Estimate the relationship between ozone and mortality within each city
- Stage 2
  - Combine the city-specific estimates to generate a national estimate, taking into account the uncertainty of each city's estimate

Stage 1: Community-Specific Model

Mortality for a given city on a given day

Ozone levels on that day and previous days

Day of the week

Time / long-term trends

$$\ln\left(E\left[\mu_t^c\right]\right) = \sum_{l=0}^{L} \beta_l^c x_{t-l}^c + \gamma^c DOW_t^c + S_t^c\left(time_t, df_t\right)$$

Temperature

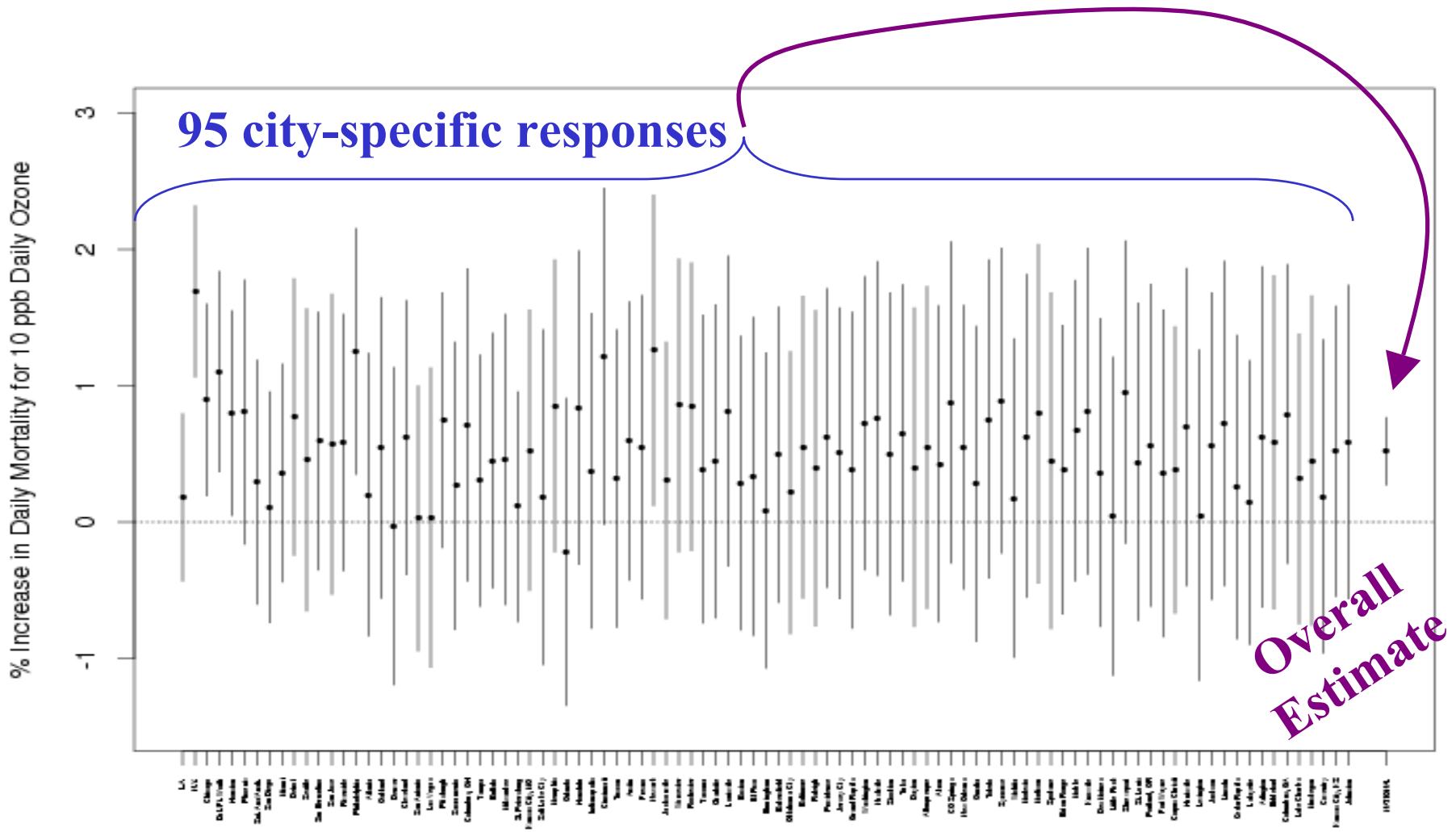
Heat waves

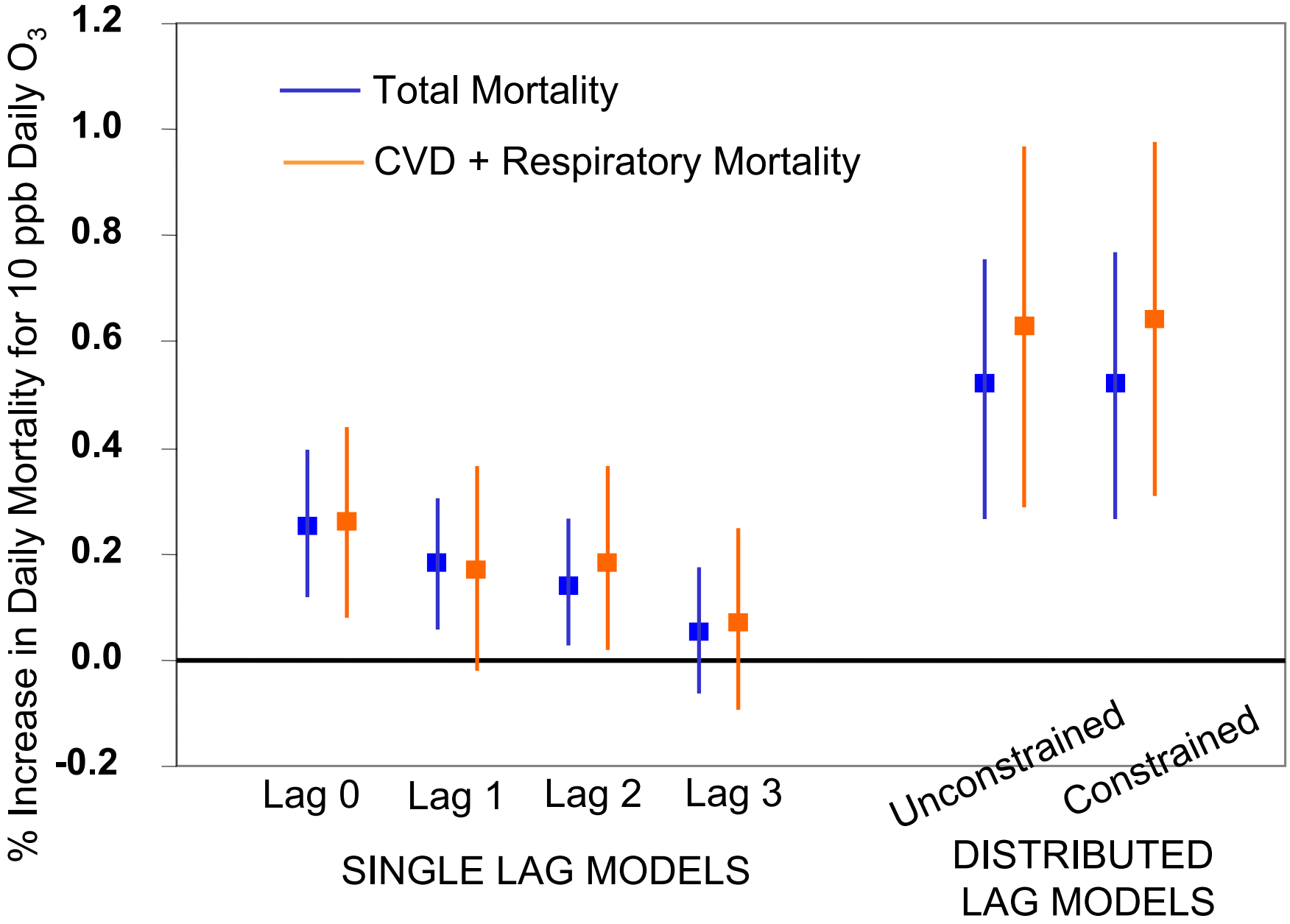
$$+ S_T^c\left(T_t^c, df_T\right) + S_{T_{1,3}}^c\left(T_{t-1,t-3}^c, df_{T_{1,3}}\right)$$

Dew point on that day and recent days

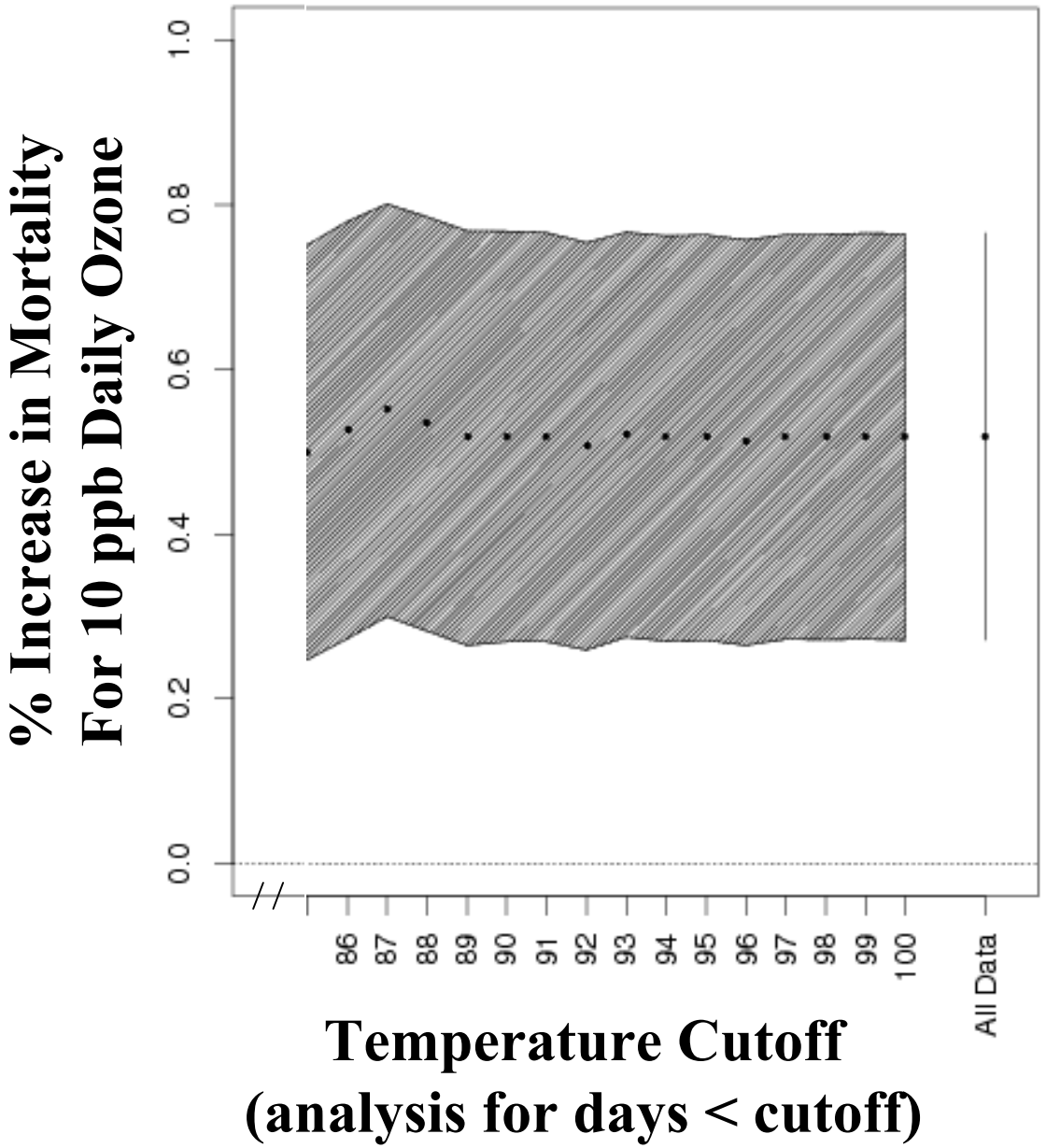
$$+ S_D^c\left(D_t^c, df_D\right) + S_{D_{1,3}}^c\left(D_{t-1,t-3}^c, df_{D_{1,3}}\right)$$

Community-Specific Bayesian Estimates




% Increase in Daily Mortality for 10 ppb Daily O_3
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
Total Mortality
CVD + Respiratory Mortality
Lag 0
Lag 1
Lag 2
Lag 3
SINGLE LAG MODELS
Unconstrained
Constrained
DISTRIBUTED LAG MODELS

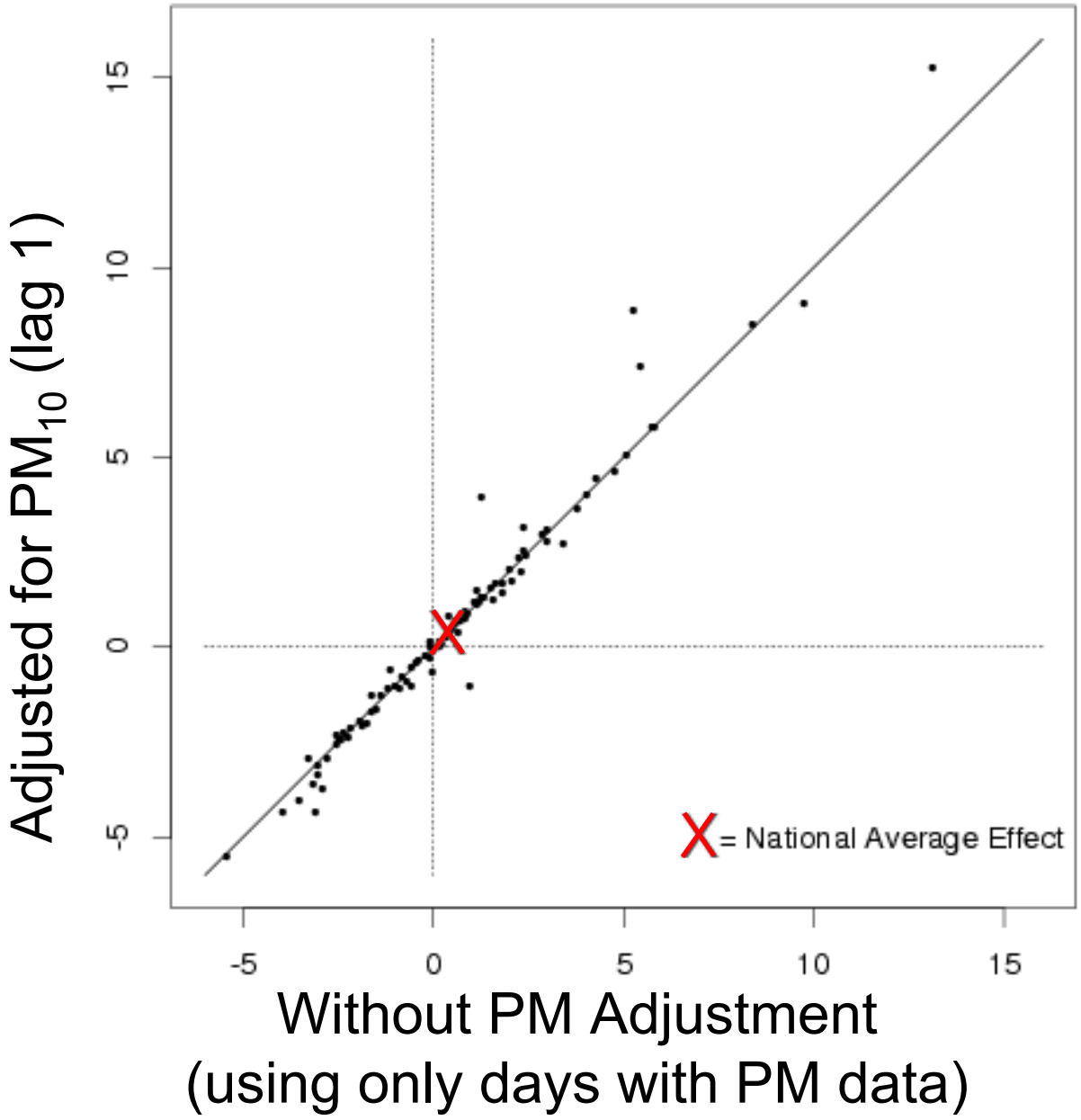
Exclude Days with High Temperatures



- Results robust to exclusion of high temperature days

- Effects range from:
  0.50% (0.25, 0.75%)
  to
  0.55% (0.30,0.80%)

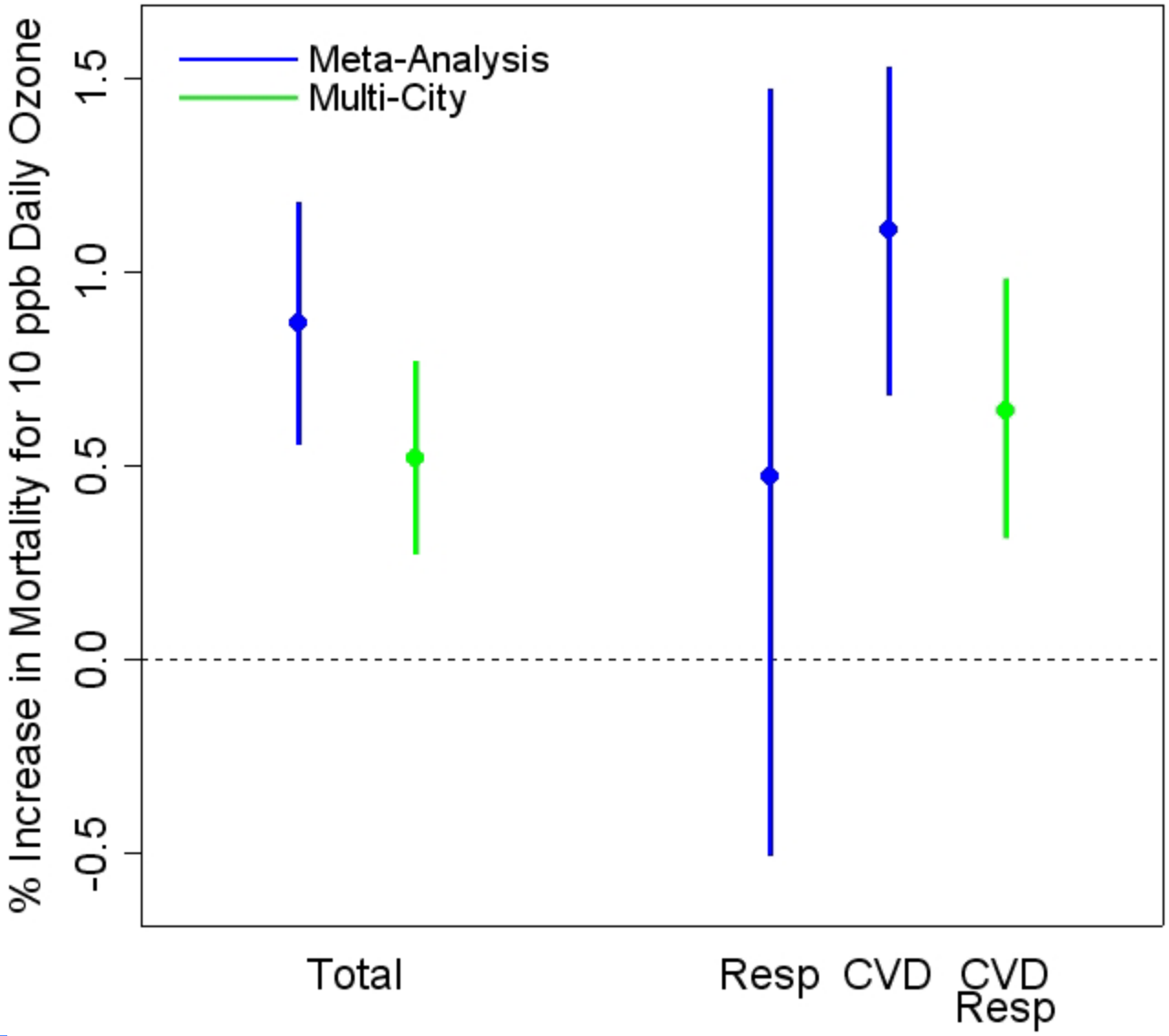
Sensitivity to Adjustment by PM_{10}

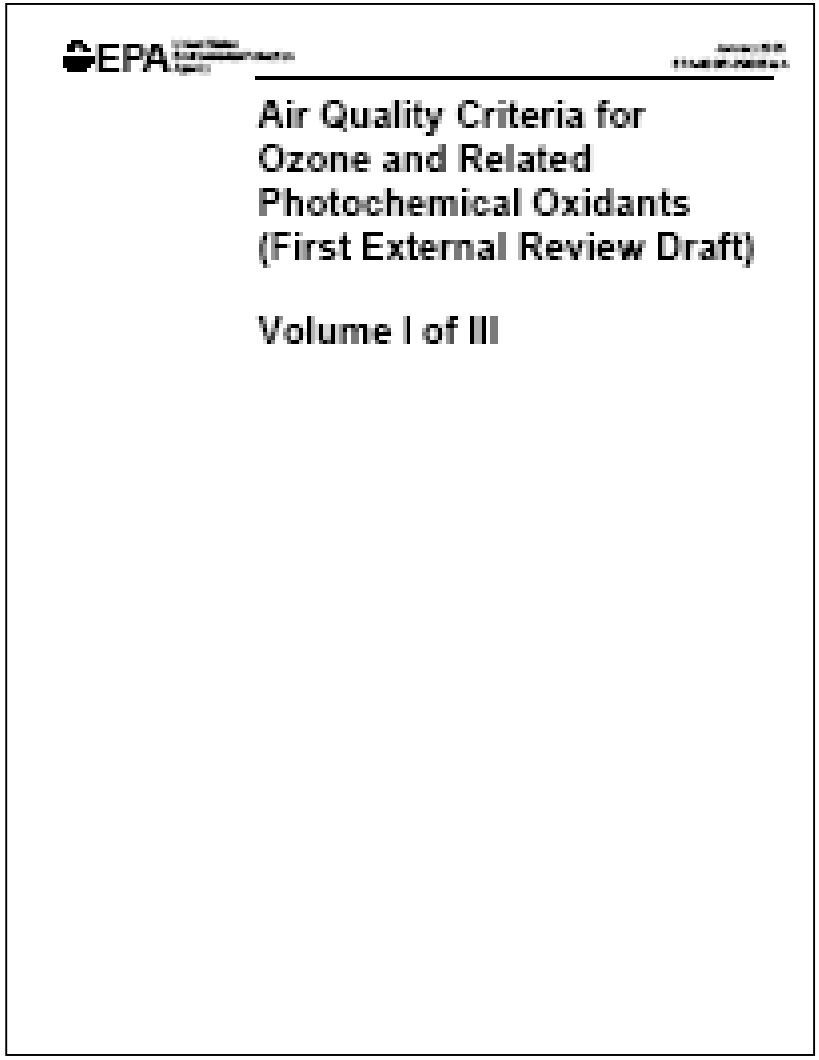


Selected Multi-City Study Results

- 95 U.S. urban communities over 14 years
- Identified a strong statistically significant association between ozone and mortality
- Effects present for O_3 on the present day, previous day, and up to about a week
- Effects similar for all age groups considered
- Results robust to adjustment by PM_{10}, degrees of freedom for smooth functions of time, and temperature
- Association present even when considering only days below EPA's current standard

Compare Meta-Analysis and Multi-City Results



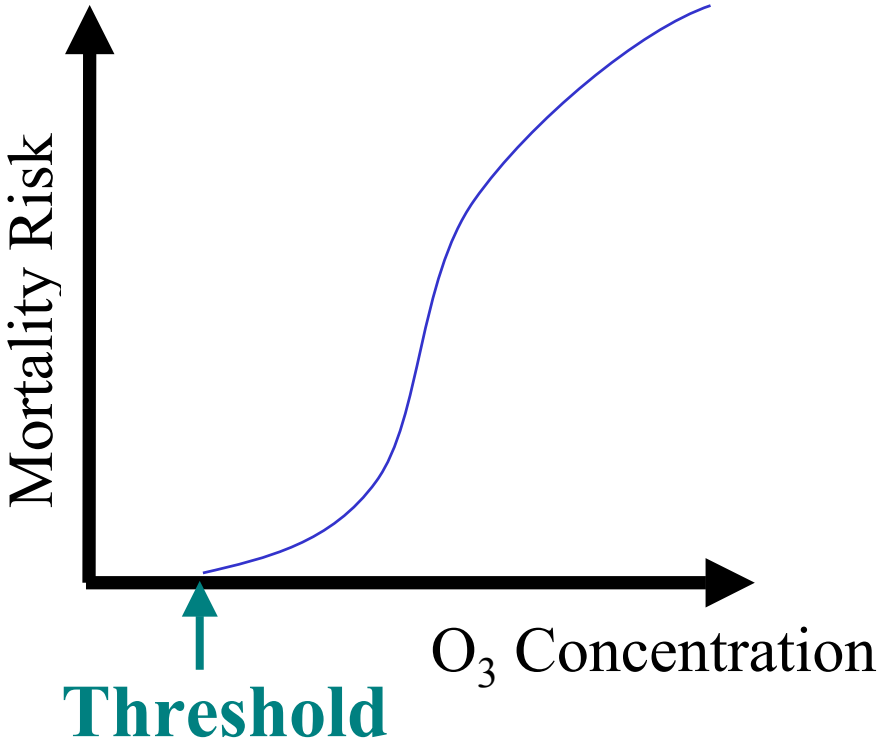


Mortality now (tentatively) included as a health endpoint.

Source: EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants DRAFT*. **2005**

Future Research Directions

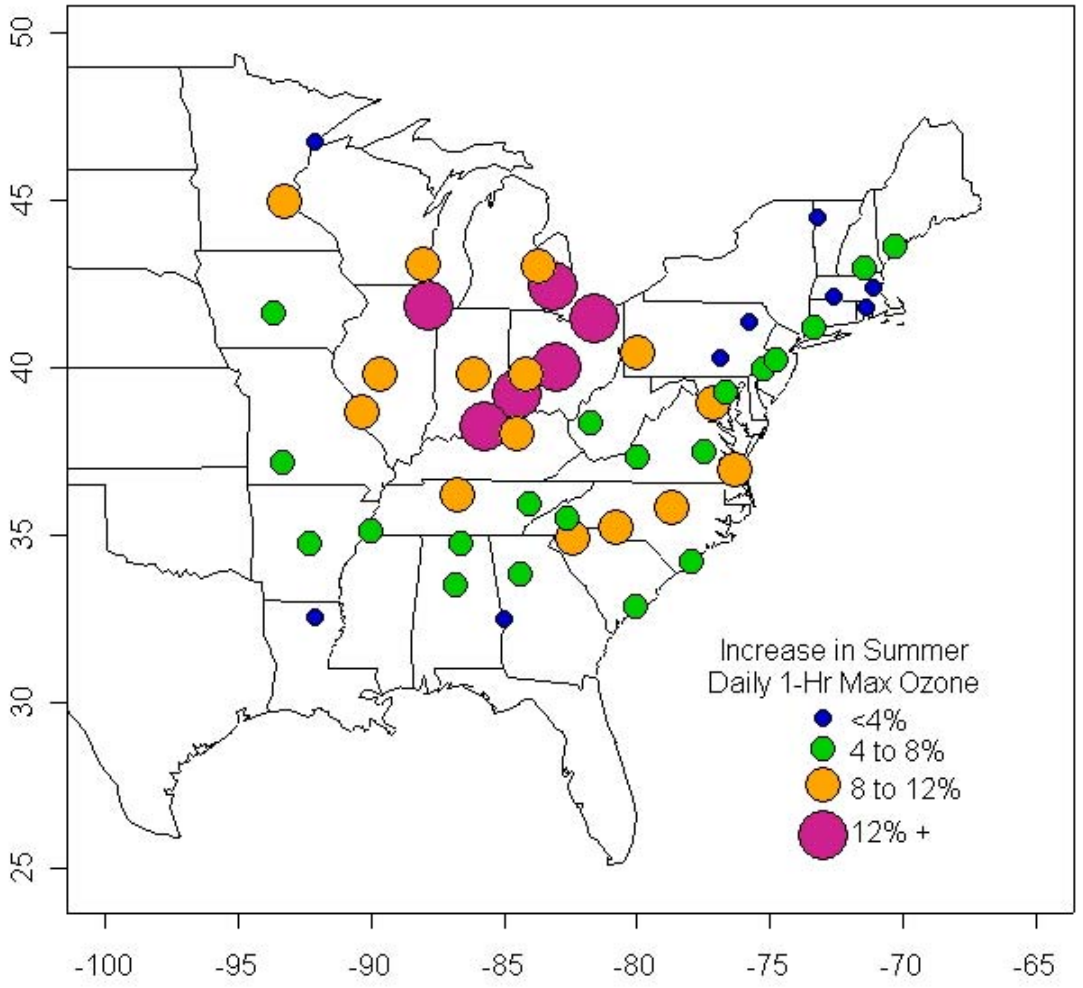
- Ozone threshold studies



Future Research Directions

- Ozone threshold studies
- Climate change and ozone

Summer Ozone Levels (2050's vs. 1990's)



Future Research Directions

- Ozone threshold studies
- Climate change and ozone
- Particulate matter speciation
- Mortality and air pollution in Latin American urban centers

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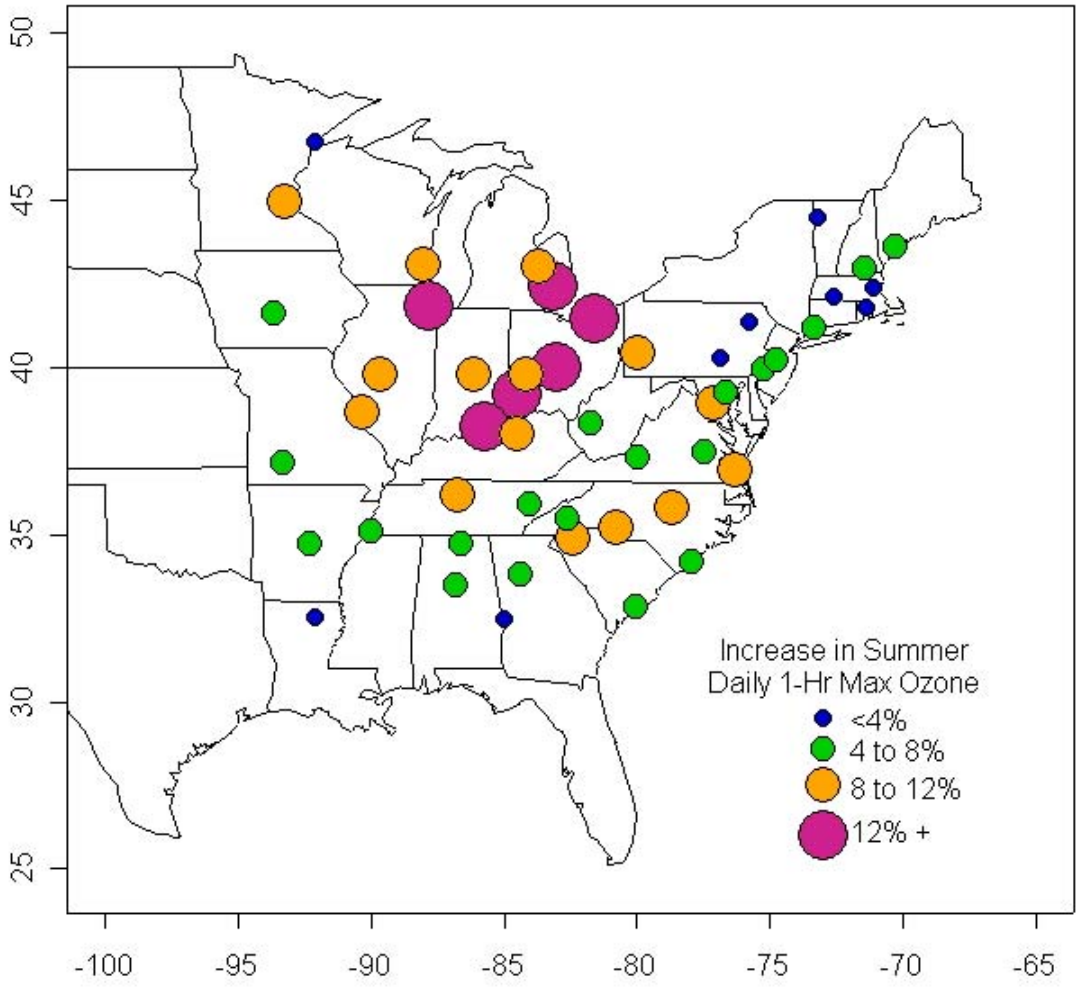

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